LCA Case Studies

LCA Application to Integrated Waste Management Planning in Gipuzkoa (Spain)

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Abstract

Goal, Scope and Background. Gipuzkoa is a department of the Vasque Country (Spain) with a population of about 700,000 people. By the year 2000 approximately 85% of municipal solid waste in this area was managed by landfilling, and only 15% was recycled. Due to environmental law restrictions and landfill capacity being on its limit, a planning process was initiated by the authorities. LCA was used, from an environmental point of view, to assess 7 possible scenarios arising from the draft Plan for the 2016 time horizon.

Main Features. In each scenario, 9 waste flows are analysed: rest waste, paper and cardboard, glass containers, light packaging, organic-green waste, as well as industrial/commercial wood, metals and plastics, and wastewater sludge. Waste treatments range from recycling to energy recovery and landfilling.

Results. Recycling of the waste flows separated at the source (paper and cardboard, glass, light packaging, organic-green waste, wood packaging, metals and plastics) results in net environmental benefits caused by the substitution of primary materials, except in water consumption. These benefits are common to the 7 different scenarios analysed. However, some inefficiencies are detected, mainly the energy consumption in collection and transport of low density materials, and water consumption in plastic recycling. The remaining flows, mixed waste and wastewater sludge, are the ones causing the major environmental impacts, by means of incineration, landfilling of partially stabilised organic material, as well as thermal drying of sludge. With the characterisation results, none of the seven scenarios can be clearly identified as the most preferable, although, due to the high recycling rates expected by the Plan, net environmental benefits are achieved in 9 out of 10 impact categories in all scenarios when integrated waste management is assessed (the sum of the 9 flows of waste). Finally, there are no relevant differences between scenarios concerning the number of treatment plants considered. Nevertheless, only the effects on transportation impacts were assessed in the LCA, since the plant construction stage was excluded from the system boundaries.

Conclusions. The results of the study show the environmental importance of material recycling in waste management, although the recycling schemes assessed can be improved in some aspects. It is also important to highlight the environmental impact of incineration and landfilling of waste, as well as thermal drying of sludge using fossil fuels. One of the main findings of applying LCA to integrated waste management in Gipuzkoa is the fact that the benefits of high recycling rates can compensate for the impacts of mixed waste and wastewater sludge.

Recommendations and Outlook. Although none of the scenarios can be clearly identified as the one having the best environmental performance, the authorities in Gipuzkoa now have objective information about the future scenarios, and a multidisciplinary panel could be formed in order to weight the impacts if necessary. In our opinion, LCA was successfully applied in Gipuzkoa as an environmental tool for decision making.

Keywords: Integrated waste management; mixed waste; recycling; transport; wastewater sludge

Glossary

ER:	Energy recovery
GIWMP:	Gipuzkoa Integrated Waste Management Plan
HW:	Household Waste
ICAN:	Institut Català de l'Energia
ICW:	Industrial and Commercial Waste
IW:	Industrial Waste
IWM:	Integrated Waste Management
MBP:	Mechanical-Biological Pre-treatment
MRF:	Material Recovery Facility
MSW:	Municipal Solid Waste
RDF:	Refuse Derived Fuel

Introduction

Gipuzkoa is a department of the Vasque Country (Spain) with a population of about 700,000 people. By the year 2000, about 400,000 tonnes of municipal solid waste (MSW) were produced. Approximately 85% of this waste was managed by sanitary landfilling, and only 15% was recycled.

Due to environmental law restrictions and landfill capacity being on its limit, a planning process was initiated by the authorities (Diputación Foral de Gipuzkoa). The Plan was intended to deal not only with household MSW, but also with commercial MSW, as well as with some industrial waste, like wastewater sludge. Therefore, the aim of the planners was to create an integrated waste management (IWM) system, with a reference time horizon of 15 years.

The authorities decided that LCA could be used as an environmental tool for decision making, to complement economic and social assessments. Through 2001, in parallel to the elaboration of the Gipuzkoa Integrated Waste Management Plan (GIWMP), our research group from ICTA applied LCA to different scenarios arising from the first draft of the GIWMP for the 2016 time horizon.

1 Purpose

Several objectives were set:

- To identify and quantify the environmental impacts produced by all the waste management processes included in the GIWMP.
- To compare, from an environmental point of view, seven alternatives for integrated waste management in the time horizon of 2016. These alternatives involved differences in waste treatment as well as in number of treatment plants and waste logistics.
- To suggest measures for environmental improvement of the whole waste management system.

2 Scope of the Work

2.1 Waste flows and quantities produced

Although the object of the study was an IWM system, the different waste flows were studied independently in the LCA, in order to assess their environmental performance. Finally, the results were aggregated for all the flows, to assess the different IWM strategies. In particular, nine waste flows were studied, including household waste (HW), industrial-commercial waste (ICW), and industrial waste (IW):

- 7 source separated waste types: paper and cardboard (HW-ICW), glass (HW-ICW), light packaging[1] (HW), organic and green waste (HW-ICW), wood (HW-ICW), plastics (HW-ICW), and metals (HW-ICW).
- Sludge from municipal wastewater treatment plants (IW).
- Commingled collection of mixed waste (HW-ICW).

Taking into account the evolution of both the population and the per capita generation of waste, as well as the regional projects for wastewater plant construction, total waste production for 2016 was estimated at 570,000 tonnes (**Table 1**).

Table 1: Waste flows included in the LCA and estimated production for 2016

Waste flows	Tonnes	%
Source separated paper-board (HW-ICW)	93,222	16.3
Source separated glass bottles (HW-ICW)	27,714	4.9
Source separated light packaging (HW)	15,103	2.6
Source separated organic and green waste (HW-ICW)	21,780	3.8
Source separated wood waste (ICW)	23,627	4.1
Source separated scrap metals (ICW)	10,739	1.9
Source separated plastics (ICW)	21,479	3.8
Wastewater sludge (28% dry solids) (IW)	85,330	15.0
Commingled collection of mixed waste (HW-ICW)	271,181	47.6
Total waste generated	570,175	100.0

2.2 Alternatives for integrated waste management in 2016

Taking into account waste generation, environmental regulations at the different levels, technological possibilities, local context, potential market for recovered materials, etc., the planners proposed three preliminary groups of alternatives (**Fig. 1**). In these three groups, different treatments were proposed for mixed waste and wastewater sludge, whereas the treatment was always recycling/composting for source segregated waste, depending on the nature of the waste. Furthermore, in each of these three groups of strategies, different possibilities were determined regarding the need for one or more treatment plants in the area under study. Regardless of the economic consequences, the number of treatment plants could affect waste logistics, and therefore energy consumption related to transport as well as materials and energy invested in building the plants.

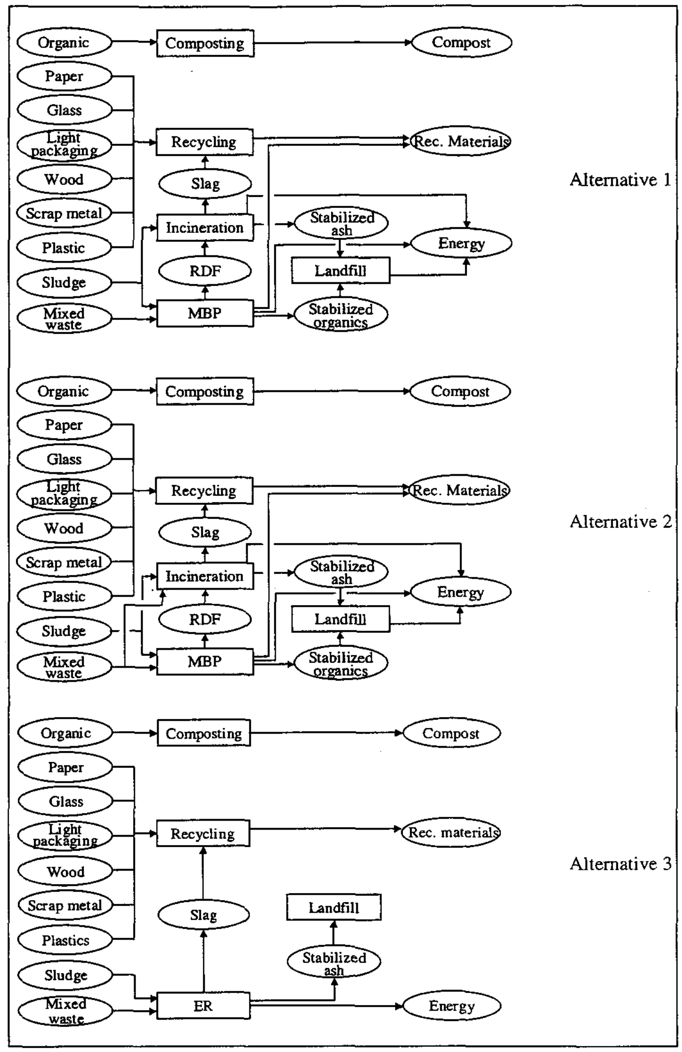

Fig. 1: Flow diagrams for the three groups of alternatives proposed in the Plan

The total number of alternatives was seven, whose main characteristics are shown in **Table 2**. As can be seen, recycling/composting schemes are constant in all of them, whereas mixed waste and sludge treatment could be:

a) Mechanical biological pre-treatment (MBP) followed by energy recovery (ER) of refuse derived fuel (RDF), or
b) Mass-burn ER.

In both cases, landfilling of the final waste produced (either stabilized organics from MBP or filter ash from ER) was considered, as well as bottom ash recovery for further use in road construction. These two waste flows, mixed waste and sludge, were also the ones affected by the different number of treatment plants. Also a combination of treatments was considered (alternative 2); in this case, the eastern and western part of Gipuzkoa applied treatments b) and a), respectively. This option was taken into account since the construction of an ER plant is already being proposed in eastern Gipuzkoa.

[1] Plastic, metallic, and liquid cardboard packaging.

Table 2: Analysed alternatives for IWM in Gipuzkoa 2016.

Alternative		General description	Number of treatment plants
1	1.1	All Gipuzkoa: • Recycling/composting for 7 source separated flows • MBP for mixed waste and dehydrated sludge • ER for RDF and thermally dried sludge	1 MBP 1 ER
	1.2		2 MBP 1 ER
2	2.1	All Gipuzkoa: • Recycling/composting for 7 source separated flows In eastern Gipuzkoa: • ER for mixed waste and thermally dry sludge In western Gipuzkoa: • MBP for mixed waste and dehydrated sludge • ER for RDF and thermally dry sludge	1 MBP 1 ER
	2.2		1 MBP 2 ER
3	3.1	All Gipuzkoa: • Recycling/composting for 7 source separated flows • ER for mixed waste and thermally dry/dehydrated sludge	1 ER
	3.2		2 ER
	3.3		3 ER

2.3 Function and functional unit

The main function of an IWM system is to manage different types of waste from different sources in a sustainable way, including environmental, economic and social criteria. In such a system, maximising waste valorisation is one of the goals to achieve, therefore, in parallel to the first mentioned function, there is a second function that has to be taken into account: the production of valorised products, including materials and energy. This creates a problem of allocation, which is discussed in 3.4. and 3.5.

The functional unit chosen was the management of the total amount of waste estimated in the Draft Plan for Gipuzkoa to be produced in 2016 (see Table 1), that is 570,175 tonnes.

2.4 System boundaries

Production and further use of fuels, electricity, and auxiliary materials (for instance, chemical products used for pollution removal at ER plants) were included. Capital equipment, such as bins, buildings, trucks, etc. were excluded from the system. This is a limitation that should be borne in mind in the conclusions, when comparing the overall environmental impact of the different scenarios, since the number of waste treatment plants is variable.

All processes involved in waste management, starting at the point the raw waste is picked up from the bins until the last non-valorisable waste is landfilled, were carefully studied. These processes include:

- Collection and transport of mixed waste, recyclables, and sludge
- Transfer and transport of these wastes
- Raw waste treatment, recycling and composting
- Secondary waste transport
- Secondary waste treatment (landfilling)

Another issue affecting the system boundaries is material and energy recovery. The IWM system delivers useful products in the form of recycled materials and electricity/heat, which have to be allocated. The approach taken in the study was to expand the system boundaries to include an alternative way of producing those energy and materials; the environmental burdens of alternative production were then subtracted to the system. The methodology followed is discussed in the next paragraphs.

2.5 Avoided products

Substitutes for recovered materials and energy obtained from waste are mainly products derived from natural resources, usually having higher environmental burdens as compared to waste recovery. By subtracting these environmental burdens to the IWM system, the resources and emissions saved by waste valorisation are quantified. In **Table 3**, the products from waste valorisation and the substitutes assumed in the study are summarised.

Table 3: Products obtained from the IWM system and substitutes assumed.

Product obtained	Substitute assumed
Materials	
Recovered paper and cardboard (sorted and baled)	Mechanical Pulp
Recovered glass (sorted and crushed)	Materials for virgin glass production (quartz sand, soda, dolomite, feldspar) and energy saved in the furnace (natural gas assumed)
Recycled PE, PET and PVC (sorted and granulated)	Virgin PE, PET and PVC resins
Ferrous metals (sorted and baled)	Pig iron
Aluminium (sorted and baled)	Raw aluminium
Wood (sorted and shredded)	Virgin shredded wood
Compost	N, P, and K fertilisers
Energy	
Electricity	Marginal mix for electricity production in Spain
Heat	Natural gas

When dealing with substitution in LCA, attention has to be paid to the point where the system is cut (e.g. in the case of paper and cardboard, if we cut the system at the material recovery facility, then the obtained product, secondary fibres, does not substitute paper, but pulp, its raw material). Furthermore, there is the question as to what extent the recycled materials can perform in the same way virgin materials do. In the study an attempt was made to quantify equivalency factors between some recovered and virgin materials. In particular, it was assumed that 1 kg of recovered paper was equivalent to 0.75 kg of virgin pulp (1:0.75), meaning that 25% of the fibres are useless due to use and shortening (Grant et al. 2001); for liquid cardboard, which is also recycled by the paper industry, it was assumed a factor of 1:0.56, since approximately 75% of this material is paper, of which only 75% is recoverable for new paper production. Compost was assumed to replace mineral N, P, and K fertilisers, using the relative content of these nutrients in both the compost and the fertilisers as equivalency criteria; the equivalency factors for compost: fertiliser were quantified as 1:0.078, 1:0.031 and 1:0.022 for N, P, and K, respectively. The remaining materials were not given a specific equivalency factor, therefore 1:1 was assumed. For metals this may be acceptable, but not for plastics, the quality of which is known to decrease after use. However, this substitution factor has been used in previous studies (Grant et al. 2001, Finnveden et al. 2000).

Substitutes for recovered energy do not require an equivalency factor, as (useful) energy doesn't lose quality. Instead, the problem is to find out what energy source/s is/are being replaced. In the study, recovered heat was assumed to replace natural gas, whereas an attempt was made to define a 'marginal mix' for electricity production in Spain for electricity, since the actual mix is constituted by such technologies as nuclear power, that show little elasticity when other sources (like waste treatment plants) deliver electricity to the grid. As a very rough estimate, the marginal mix was defined as 70% hydraulic, 25% coal, and 5% natural gas (ICAEN, private communication).

2.6 Data sources and quality

A considerable amount of data was needed to carry out a study dealing with such a high number of processes and waste types. As a consequence, data sources were numerous and quality variable.

Fuel consumption related to collection and transport of waste was modelled with a specifically designed Excel spreadsheet, taking into account the transport distances and waste production from the 89 municipalities in Gipuzkoa. This model also distinguished between collecting the garbage (urban consumption) and transporting it (road consumption), using either collecting trucks or transfer trucks (including the energy consumption of the transfer station, using local data). This approach was the best available, since it was not possible to obtain enough data from the local contractors to calculate actual consumptions; anyway, the waste logistics proposed in the Plan were completely different from the current ones, so modelling had to be done.

Mass and energy balances for waste treatment processes were calculated using several data sources, which are presented in detail in **Table 4**. In practice, most of the processes were modelled using more than one data source, since few single sources covered all the relevant environmental aspects to be included in each process.

Table 4: Summary of data sources.

Data	Sources
Collection and transport of waste	Excel spreadsheet developed for this study, including collection, transfer, and transport; Local data on transfer stations.
Fuels, electricity (consumed and avoided)	BUWAL 132, 250, and 300 (Habersatter et al. 1991, 1996; Dall'Acqua 1997); ETH 96 (Frischknecht et al. 1996).
MRFs (paper, glass, light containers)	Mass and energy balances of Spanish plants, collected directly by our research group; Local data on material balance of light container recovery.
Composting	Mass and energy balances of Spanish plants, collected directly by our research group. Literature: Smet et al. 1999.
Plastic reprocessing	Literature: Grant et al. 2001; Heijningen et al. 1992.
Wood waste recycling	Local data on wood shredding.
Incineration	Literature: Kremer et al. 1998; Emission limits from Directive 2000/76.
Stabilization of incineration residues	Data on slag stabilization from the incineration plant in Tarragona (Spain); Data on fly ash stabilization from a Spanish company (ECOCAT), collected directly by our research group.
MBP	Mass balance defined by the GIWMP (Diputación de Gipuzkoa 2002); Energy balance from the plant in Amiens, France; Cogeneration emissions from White et al. 1995.
Landfilling	Local data on leachate composition (Gómez et al. 1997); Previous studies by our research group (Domènech et al. 1997); Literature: White et al. 1995; Nielsen et al. 1998; Bez et al. 1998; Höglund 1997.
Thermal drying of wastewater sludge	Local data on projected facilities; Literature: Sernagiotto 1999.
Materials (consumed and avoided)	BUWAL 132, 250, and 300 (Habersatter et al. 1991, 1996; Dall'Acqua 1997); Delft University of Technology 1996; Steinhage 1990; Davis et al. 1999.

2.7 Life Cycle Impact Assessment

LCIA was conducted until characterisation. The following impact categories and indicators were used:

- Abiotic Resource Depletion (ARD): kg antimony eq. (Guinée et al. 2001)
- Global Warming Potential (GWP): kg CO_2 eq. (Houghton et al. 1994)
- Acidification Potential (AP): kg SO_2 eq. (Heijungs et al. 1992)
- Ozone Depletion Potential (ODP): kg CFC-11 eq. (WMO 1992)
- Human Toxicity Potential (HTP): kg 1,4-dichlorobenzene eq. (Huijbregts 1999)
- Eutrophication Potential (EP): kg phosphate eq. (Heijungs et al. 1992)
- Photochemical Ozone Formation Potential (POFP): kg ethene eq. (Hauschild & Wenzel 1998)
- Energy Consumption (EC): indicator measured in MJ primary energy used
- Water Consumption (WC): indicator measured in litres. Includes all water used in the system
- Final Waste Production (FWP): indicator measured in kg waste to be landfilled, regardless of the type of waste

3 Results

The results of the study are grouped in three main topics:

- Selective collection and recycling: the results for the seven source separated kinds of waste are discussed together, being that these results are common to all the alternatives analysed.
- Options for mixed waste and sludge management: here, the different alternatives for management of these two waste flows are compared.
- Options for IWM: the overall result for recycling plus the corresponding option for mixed waste and sludge are aggregated, thus obtaining the overall environmental impact of the seven IWM alternatives.

3.1 Environmental benefits of material recycling

As can be seen in **Fig. 2**, material recovery through selective collection of inorganic as well as organic waste results in net environmental benefits (avoided impacts > produced impacts). The results for the sum of seven source separated waste flows show this pattern, except for the indicator WC (see section 3.2.). The flows contributing more to these benefits are paper and cardboard, plastics, metals, and light packaging.

These results are remarkable, since selective collection of waste is common to all the alternatives analysed. As a consequence, all alternatives show these benefits.

Two factors mainly influence these results: a) the net environmental benefit of recovering a certain material, and b) the total amount to be collected. The higher the net benefit per kg and the amount collected, the higher the benefit in the system. This explains the relative contributions of the different materials. Paper and cardboard are supposed to be collected in big amounts, having then an important contribution to the overall benefits. The relative importance of plastics, however, is mainly due to a high net benefit per kg recovered. In this point it should be borne in mind that recycled plastics were assumed to replace virgin plastics 1:1, which may be an overestimation.

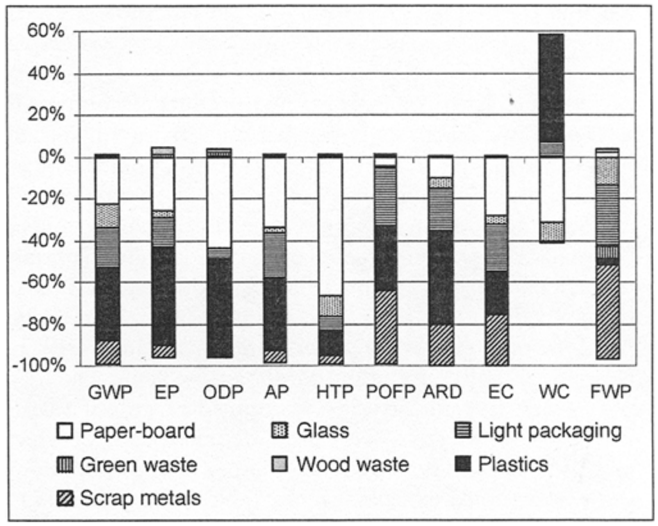

Fig. 2: Environmental profile of the seven source separated waste flows, showing net environmental benefits except in WC

3.2 Inefficiencies detected in recycling schemes

A high energy consumption has been detected for collection and transport of some fractions. The worst case is plastics, having a fuel consumption estimated at 37 litres diesel/tonne collected. The reason for this is the low density of these materials. In most of the waste flows, collection and transport is the main source of impact, rather than treatment.

A special case is plastic recycling, which shows a high impact in the indicator WC (see Fig. 2), due to water consumption in mechanical reprocessing of recovered plastics.

3.3 Options for mixed waste and wastewater sludge

Fig. 3 shows the results of characterisation for the seven alternatives for mixed waste and sludge management. For an easier interpretation of the graphics, alternatives being part of the same group (same treatment, but different number of treatment plants) are displayed in the same colour. From this figure it can be seen that Group 1 (in white) shows the best environmental performance in the following impact categories and indicators: GWP, ARD, AP, ODP, HTP, EP, EC, and WC. On the other hand, group 3 (in black) appears to be better in FWP and POFP. Since group 2 is actually a combination of the strategies proposed for the groups of alternatives 1 and 3, its results are intermediate, that is, its impact is always between the values obtained for 1 and 3.

The reasons for better performance of group 1 is that MBP allows for a certain degree of material recovery, as well as energy recovery through biogas production; ER is also better in group 1, due mainly to RDF burning instead of mass burn. On the other hand, group 3 is mainly based in ER, so less volume of waste has to be landfilled; this allows a better performance in FWP. Furthermore, the landfilled waste is inorganic (filter dust/ash); on the contrary, in group 1, part of

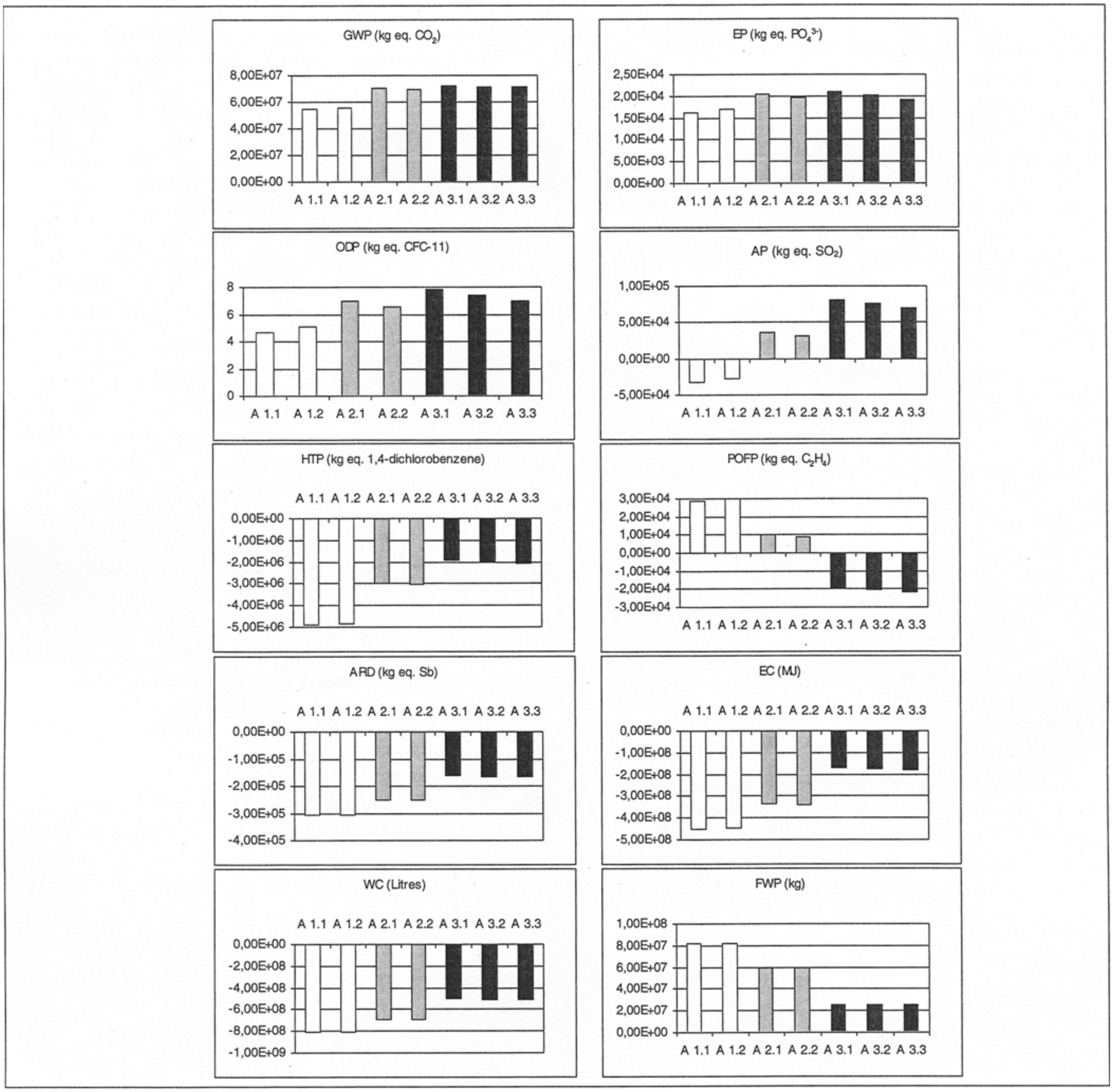

Fig. 3: Characterisation results for the seven alternatives proposed for mixed waste and wastewater sludge management

the landfilled waste is stabilized organic material from MBP, which can still potentially produce methane, a contributor to POFP. In the study, it was assumed that MBP reduced landfill gas emissions by about 50% (White et al. 1995) as compared to raw organic matter. Further reduction would have led to less differences between alternatives in POFP.

3.4 Logistics

No relevant differences between alternatives for mixed waste and sludge were found in the results concerning the number of treatment plants considered. This can also be seen in Fig. 3. For instance, there are no remarkable differences between alternatives 1.1 and 1.2, or between 3.1, 3.2 and 3.3. Although transport impact decreases almost 20% in alternatives 2.2 and 3.3, the main source of impact is waste treatment, so the overall results remain similar. However, it must be borne in mind that only the effects on transportation distances were considered in the scenarios, and construction of the plants themselves was not included.

3.5 Sources of impact in mixed waste and sludge management

Incineration, either for RDF or mass burn, is the main source of impact in all categories, although RDF burning is more efficient because the higher energy content of waste allows

a better energy recovery, and so the avoided burdens of energy products (electricity and heat) are also higher.

Except in GWP and EP, more than 50% of the environmental impact of incineration is attributed not to stack emissions, but to other aspects, highlighting the electricity consumed from the grid (when the plant is stopped for a technical checking), and auxiliary materials such as caustic soda and cement. The relative relevance of these aspects is explained by the fact that the plant was assumed to comply with the Directive 2000/76/CE, which is very restrictive about air emission limits. Therefore, the relative 'cleanness' of the emitted gases makes the remaining aspects become more relevant.

Another relevant source of impact is thermal drying of dehydrated sludge prior to transportation. This was due to a high energy consumption in the form of natural gas, used to evaporate the water in the sludge. This process was proposed to be carried out by cogeneration, obtaining an electricity surplus that would be sold to the grid, so again avoided burdens of external electricity had to be subtracted. In some impact categories, such as AP and EP, a net benefit is achieved, but the impact is not compensated in the remaining categories. Furthermore, if we consider that transport of sludge (either dehydrated or dried) has a small contribution to all categories, the environmental convenience of thermal drying is questionable, since the transport savings are rather small. It is true, however, that sludge has to be dried before incinerating, but this could be done after transporting it, as a previous step to incineration, using the waste heat from the energy recovery system in this plant.

Landfilling of stabilized organic materials from MBP also shows an important contribution to the POFP category, as mentioned above (see 4.3.), because of the potential methane emissions released from degradable solids. Surprisingly, the contribution of these emissions to GWP were rather moderate (about 25% of the total GWP). The reasons are partly the emission reduction achieved by MBP, and, more important, the large contribution of fossil CO_2 emissions produced by RDF combustion.

3.6 Integrated waste management

The aggregation of all waste flows for each alternative leads to the whole picture, that is integrated waste management in Gipuzkoa, whose characterisation results are displayed in **Fig.** 4 and 5.

In Fig. 4, the contribution to the impact categories and indicators is shown. In fact, as there are seven different alternatives, seven different graphics could be shown in Fig. 4. Nevertheless, the environmental profiles are so similar that showing just one alternative (in this case A 2.1 is displayed) is enough to see the pattern. From the figure it can be seen, in the first place, that environmental benefits are obtained (avoided impacts > produced impacts) due to waste valorisation in nine out of ten impact categories and indicators. The exception was FWP. The most important contribution to these benefits come from the source separated flows,

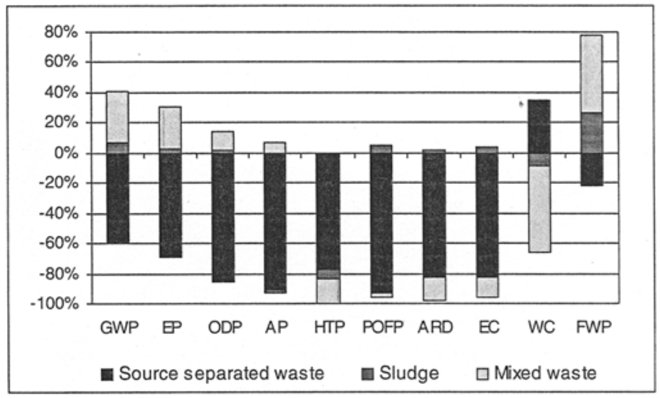

Fig. 4: Environmental profile of the integrated waste management in Gipuzkoa, using alternative 2.1 as an example

constituting 37% of the managed waste. The remaining 63% is constituted by wastewater sludge and mixed waste, the latter being the main contributor to potential impacts in several categories such as GWP, EP, ODP or FWP. A curious exception is WC, where waste recycling shows a net impact, but it is completely compensated by the savings achieved by mixed waste.

Fig. 5 shows the characterisation results for the seven options for IWM in Gipuzkoa. Here, the net environmental impact is displayed, in order to compare all the options proposed by the GIWMP. As stated above, the first aspect to highlight is that net benefits are obtained by all the alternatives in nine out of ten categories. However, from the characterisation results, it is not possible to easily identify a 'frontrunner' option. For instance, Group 3 of alternatives shows better results in FWP, whereas group 1 performs better in WC and GWP. On the other hand, the results do not show relevant differences in the remaining categories and indicators.

4 Conclusions and Environmental Improvement

The key findings of this LCA case study can be summarised as follows:

- Source separation and further recycling of waste (paper and cardboard, glass, light containers, green waste, wood waste, plastics, and scrap metals) results in overall environmental benefits or savings, caused by substitution of virgin materials. The exception is the WC indicator, due to mechanical recycling of plastics.
- It has to be borne in mind, however, that only paper, compost and liquid cardboard were given equivalency factors for substitution of virgin materials, while the other recovered materials were assumed 1:1 substitutes. These procedures for the allocation of the avoided products, might have significant influence in the results, so further research on this issue should be carried out by the LCA community.
- Some inefficiencies were detected in the management of source separated waste. The main issue to be improved is collection and transport, since this was the stage contributing most to the impact of recycling schemes. Possible measures to improve this are to increase compaction,

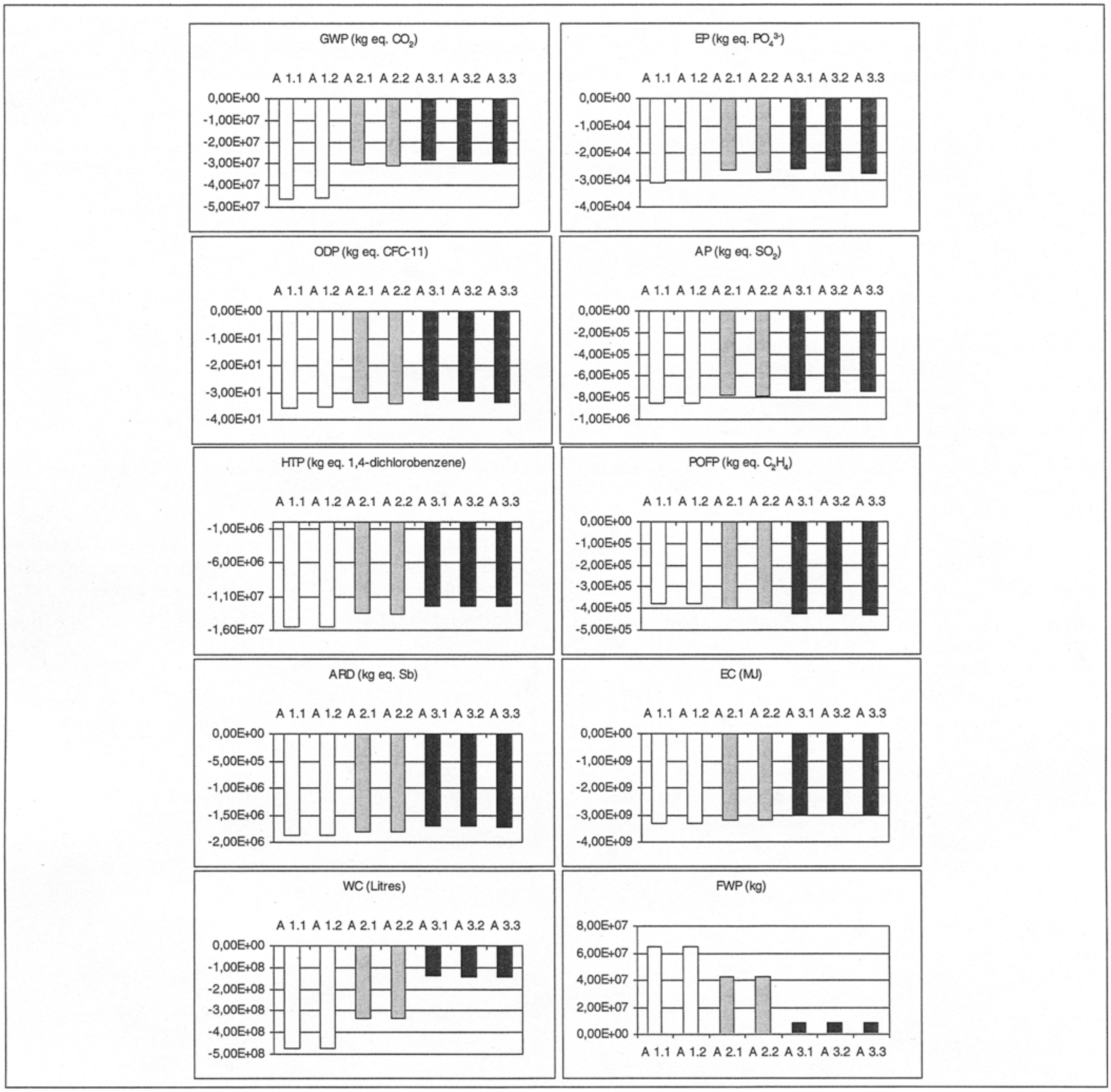

Fig. 5: Characterisation results for the integrated waste management in Gipuzkoa

the use of transfer stations, and also the use of alternative fuels, such as biofuels or natural gas. However, these are only suggestions that were not assessed in the LCA.

- Another issue, as stated above, is that plastic reprocessing consumes a lot of water. The need of washing the materials should be assessed, and closed circuits should be implemented in these plants.
- The major environmental impacts come from mixed waste and wastewater sludge management, regardless of the alternative analysed. The main processes contributing to this impact are incineration, thermal drying of sludge, and landfilling of stabilized organic material. From the results of the study, the environmental convenience of thermal drying of sludge is not clear, since further transport of this material is not a critical step. Drying of the sludge should be implemented in the incinerator plant, as a pretreatment, using waste heat from the energy recovery system.
- Integrated waste management, regardless of the alternative analysed, shows environmental benefits in all impact categories and indicators, except for FWP. This is due to the important savings achieved by source separated waste recycling, and also to the valorisation of mixed waste and sludge, by means of MBP and ER.

- There are no differences between alternatives concerning the number of treatment plants considered. Nevertheless, in the LCA only the effects on transportation impacts were assessed, since the plant construction stage was excluded from the system boundaries.
- Although no IWM alternative could be clearly identified as the one having the best environmental performance, we didn't feel like reducing the results to a single score through weighting. Instead, the authorities in Gipuzkoa now have objective information about the future scenarios, and if necessary a multidisciplinary panel could be formed in order to weight the impacts. In our opinion, LCA was successfully applied in Gipuzkoa as an environmental tool for decision making.

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